



Interactive LUROVA™ Thermal Model for the STEM Simulation Game



Presented By

Ron Creel

**Retired Apollo Lunar Roving Vehicle
Team Member**

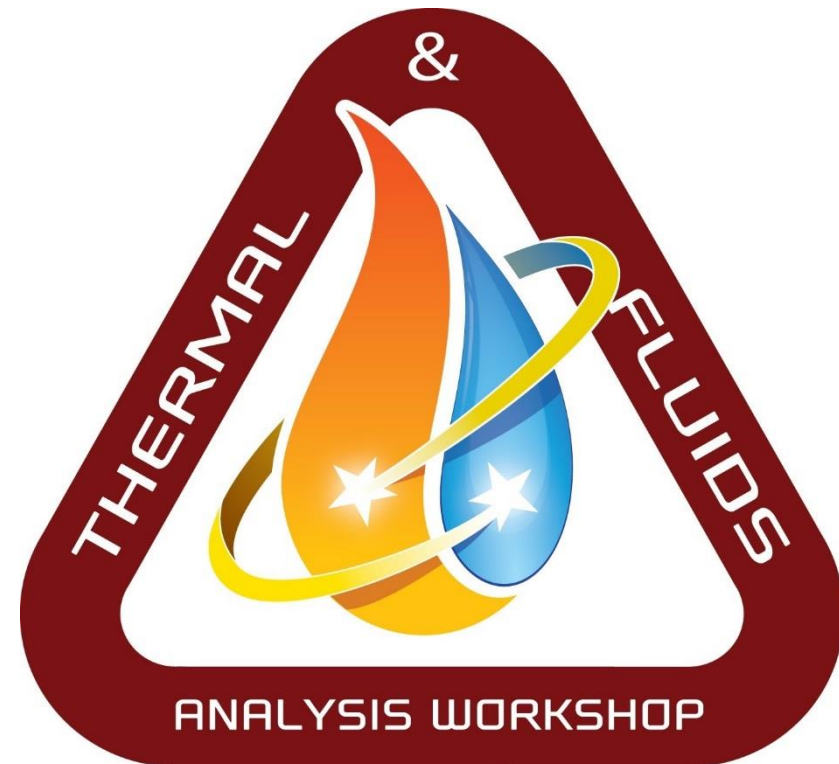
Thermal & Fluids Analysis Workshop

TFAWS 2017

August 21-25, 2017

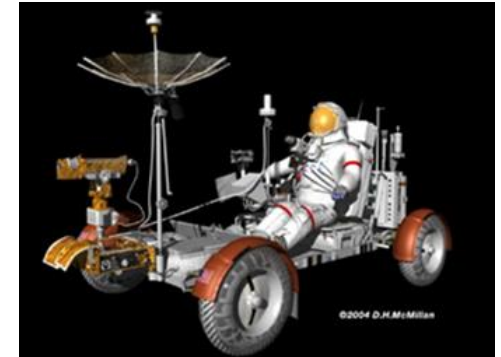
NASA Marshall Space Flight Center

Huntsville, AL

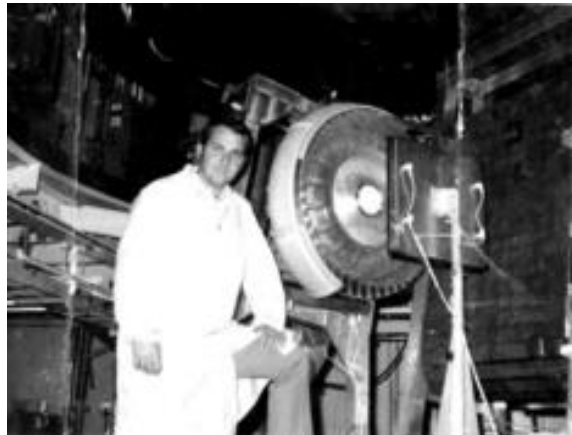


TFAWS
MSFC • 2017

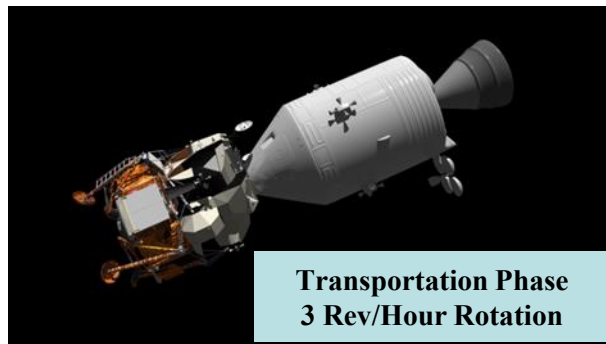
- **Apollo Lunar Rover Thermal Modeling for Mission Support**
- **LUROVA™ Thermal Modeling for TFAWS**
- **LUROVA™ Simulation Game for STEM**
- **Interactive LUROVA™ Simulation Game Thermal Model**
- **Verification / Correlation of the LUROVA™ Sim Game Model**
- **Future Plans for the LUROVA™ Simulation Game**
- **LUROVA™ Poster and Demonstration for Attendees**



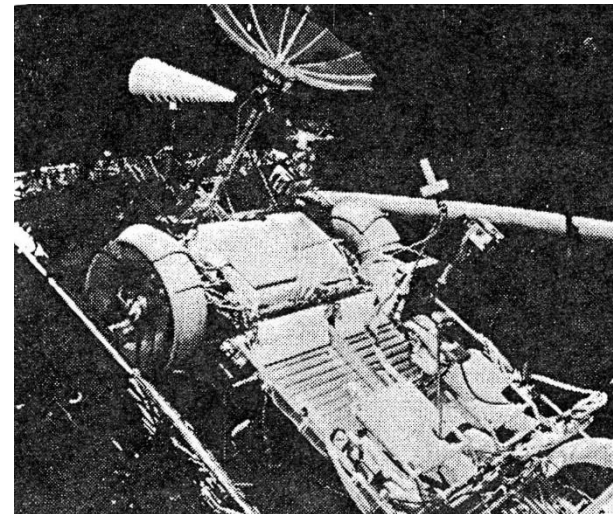
• Test Correlated Thermal Models Were Vital for Rover Success



Ron Creel with Rover Mobility TVAC Test Unit

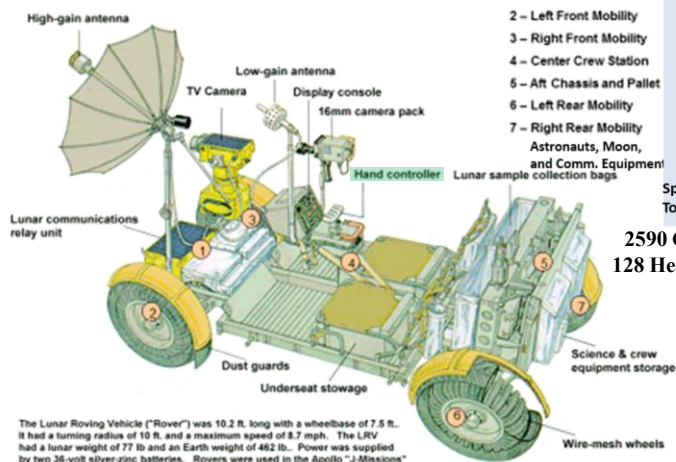


Folded Rover Modeled, but not Tested



Qualification and Flight Units TVAC

Lunar Roving Vehicle



The Lunar Roving Vehicle ("Rover") was 10.2 ft. long with a wheelbase of 7.5 ft. It had a turning radius of 10 ft. and a maximum speed of 8.7 mph. The LRV had a lunar weight of 77 lb and an Earth weight of 462 lb. Power was supplied by two 36-volt silver-zinc batteries. Rovers were used in the Apollo "J Missions" (15, 16 and 17) to greatly extend the lunar surface area explorable by the astronauts.

Sub Models

- 1 - Forward Chassis
- 2 - Left Front Mobility
- 3 - Right Front Mobility
- 4 - Center Crew Station
- 5 - Aft Chassis and Pallet
- 6 - Left Rear Mobility
- 7 - Right Rear Mobility
- Astronauts, Moon, and Comm. Equipment

Nodes

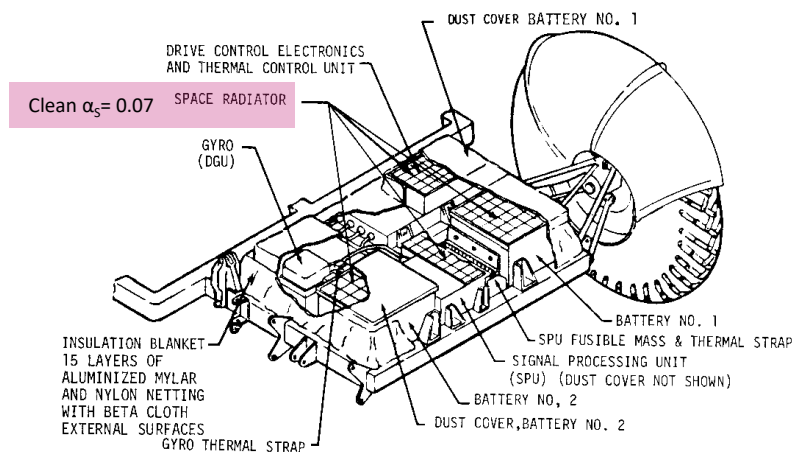
- 51
- 19
- 19
- 26
- 18
- 19
- 19
- 9

Space 1
Total 181

2590 Conductors
128 Heating Arrays



Astronaut Silver Snoopy Award for Thermal Modeling after Apollo 16 in July, 1972



181 Node SINDA Thermal Model for Apollo 15

19 Node Forward Chassis Thermal Model for Apollo 16 and 17

A photograph showing three men in a control room. They are gathered around a large screen that displays a high-resolution image of the lunar surface, showing craters and a grid overlay. One man, wearing a light blue shirt and a dark skirt, is pointing at the screen with a pen. The other two men, one in a white shirt and tie and the other in a light-colored shirt, are looking at the screen. The room has a control panel with various buttons and a television set in the background.

A man with a mustache, wearing a light-colored short-sleeved shirt and khaki pants, is seated in a grey office chair at a large, light-green control console. The console is equipped with several monitors; one in the center shows a dark, grainy image. To the right of the central monitor is a panel with six small, rectangular displays arranged in a 2x3 grid. In the foreground, a large, light-colored printer or plotter is visible, with a sheet of paper emerging from it. The background is dark, suggesting an indoor setting at night.

The graph displays temperature data for the Apollo 16 LRV. The Y-axis represents Temperature in degrees Fahrenheit (°F), ranging from 20 to 160. The X-axis represents Time in hours, ranging from 0 to 55. The graph includes three data series: Pre-landing predictions (dashed line), Crew readout (solid line), and Real time prediction (solid line with dots). The graph also shows the operating upper and lower limits. Key events are marked: Power Switching at approximately 25 hours and No Cool Down! at approximately 45 hours. The graph shows temperature fluctuations, with a peak around 110°F at 10 hours and another peak around 120°F at 30 hours. The temperature generally stays within the operating limits, except for a brief excursion above the upper limit during the 'No Cool Down!' event.

Time (hours)	Pre-landing Predictions (°F)	Crew Readout (°F)	Real Time Prediction (°F)
0	80	80	80
5	100	100	100
10	110	110	110
15	90	90	90
20	70	70	70
25	60	60	60
30	120	120	120
35	100	100	100
40	90	90	90
45	80	80	80
50	100	100	100
55	120	120	120

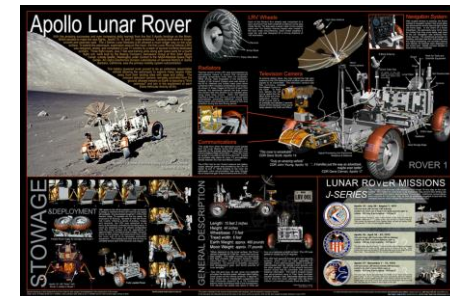
The top portion of the image is a circular map of the Moon's surface, showing the locations of the Apollo lunar landing sites. The map is marked with a grid of latitude and longitude. The landing sites are indicated by red dots and labeled: Apollo 11, Apollo 12, Apollo 14, Apollo 15, Apollo 16, Apollo 17, and Apollo 18. The bottom portion of the image is a photograph of an Apollo 16 lunar surface experiment package (ALSEP) on the Moon. The ALSEP is a complex of scientific instruments, including a seismometer, a magnetometer, and a laser altimeter, mounted on a small, white, rectangular base. The ALSEP is positioned next to a large, orange, cylindrical object, which is a part of the Lunar Module's ascent stage. The background shows the dark, rocky surface of the Moon.

APOLLO LAUNCH NO.: 17		LRY REAL TIME THERMAL PREDICTION/CORRELATION		PAGE: 217	
RUN NUMBER: 109		EVA: III <input checked="" type="checkbox"/> A <input type="checkbox"/> B <input type="checkbox"/> C/D		ALPHA: 0.85 C/LRU POWER: 0.00	
RUN DATA		ASSUMPTIONS: COV OPENED @ 6			
DATE: 12-13-72 SOL. EL. ANG. 34.5		LRY			
START TIME: 11:10 RAIL TIME: 130 °F		RAY POWER: 0.00			
COMPLETION TIME: 11:11 <input type="checkbox"/> A.M. <input checked="" type="checkbox"/> P.M.		RAY COV: 0.00			
L. AMP HR/KM: 0.64		RAY INT: 0.00			
<input checked="" type="checkbox"/> CORRELATION <input checked="" type="checkbox"/> PREDICTION <input checked="" type="checkbox"/> REAL TIME		<input type="checkbox"/> CORRELATION <input type="checkbox"/> PREDICTION <input type="checkbox"/> REAL TIME			
R. AMP HR/KM: 0.64		RAY INT: 0.00			
RANDEX FACTOR: 0.10		<input type="checkbox"/> SEE ASSUMPTIONS FOR AMP INT. OR AMP HRS/KM + 0.66			

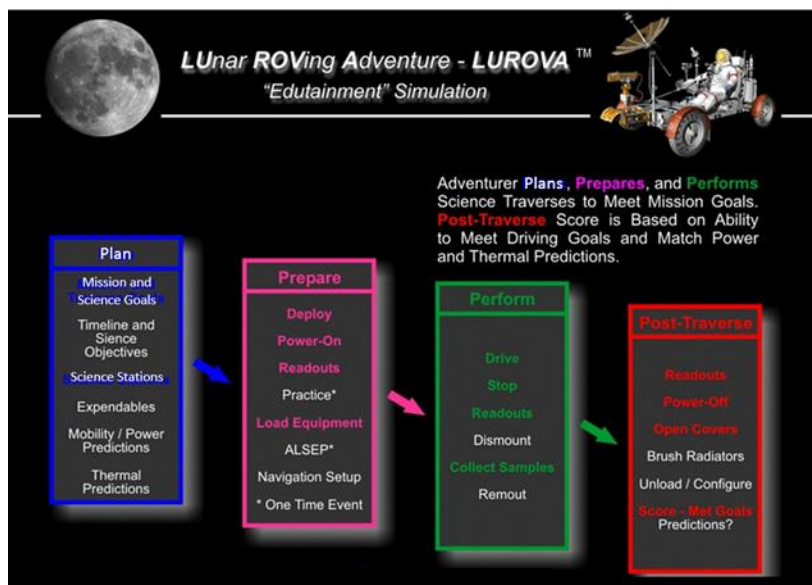
STATION NUMBER	STATION TIMES		SEQUENT DISTANCE (km)	TEMPERATURES (°F)						WAX BOXES (% Wet)			AMP. HR. L/R
	Arrival	Departure		L. Batt	R. Batt	SPU	OGU	DCE	SPU	DCE	AMP. HR.		
1. LM	0:00	0:14	0.10	100.0	120.0	100.0	130.0	60.0	1.00	0.00			
2. SEP	0:16	0:54	0.11	100.6	123.3	100.8	133.4	62.9	1.00	0.00			
3. 6	1:19	2:33	3.8	106.4	123.2	115.4	145.5	78.7	1.00	0.00			
4. 7	2:56.5	2:58	0.88	107.1	126.4	113.7	158.1	75.6	1.00	0.00			
5. 8A	3:15	4:03	1.92	113.1	130.7	121.8	157.4	84.1	1.00	0.00			
6. 9	4:20.5	5:30.5	2.75	133.0	137.1	132.6	163.0	96.0	1.00	0.00			
7. 64	5:45.5	6:25	2.95	135.0	141.5	144.5	170.1	116.2	1.00	0.00			
8. ZIP	6:25.5	n/a	0.11	140.3	147.6	150.6	173.9	109.2	1.00	0.00			

4

- **2006** – Presented Apollo Lunar Roving Vehicle mission performance and lessons learned, and introduced Rover mission support thermal models
 - Thermal models originally planned for CD to accompany retrospective book
 - 19 Node model then used for NASA Nightrover Power Storage Challenge
- **2014** – 181 node SINDA thermal model updated with render engine provided external surfaces for radiation conductors and solar heating
 - Conductors and solar heating needed to add to historical SINDA model nodes listing
 - 911,509 poster polygons reduced to 7805 polygons for TRASYS surface modeling
- **2017** – **LUROVA™** thermal model incorporated in a **Science, Technology, Engineering, and Mathematics (STEM)** simulation game for interactive student challenge and Moon exploration experience
 - Trademark purchased for **LUROVA™** Simulation Game
 - Initial game structure contributed by Computer Science associate professor and students at the University of Alabama in Huntsville (UAH)
 - Exploration realism is improved by interactive use of actual lunar terrain data collected since 2009 by NASA Lunar Reconnaissance Orbiter (LRO) spacecraft



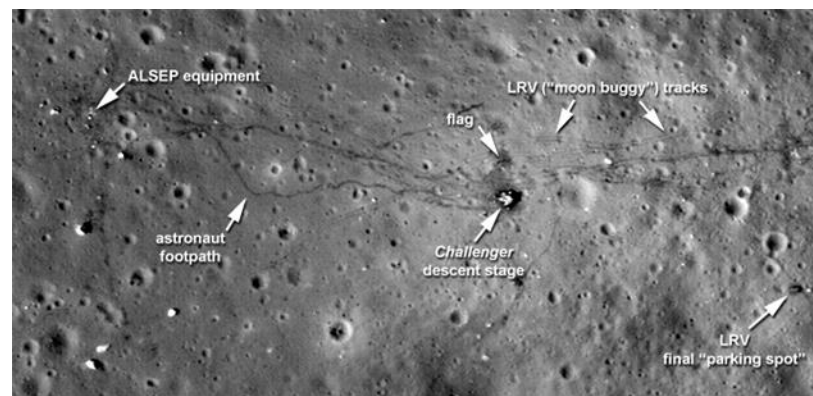
- “Simulation Game = Attempt to copy various activities from real life in the form of a game for education, training, analysis, or prediction.”



Lunar Reconnaissance Orbiter (LRO) Collecting 0.5 Meter Resolution Terrain Data Since 2009

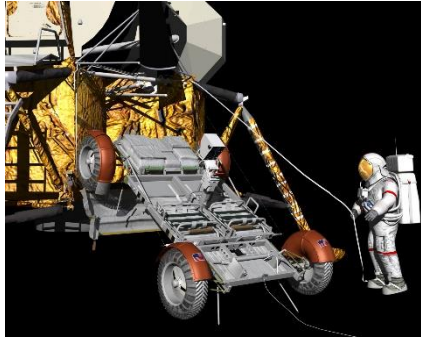
LUROVA™ STEM Simulation Game Provides Apollo Mission Support Thermal Model with High Resolution Surface Model and LRO Terrain Data

Variable Planning and Preparation for Mission Timing, Location, and Rover Configuration
Hand Controller for Driving and Steering
Battery Power Usage and Solar Heating
Component Failures and Cooldown Dust Effects



LRO Terrain Data for Apollo 17

- Adventurer Plans and Executes Exploration Traverses, and Views:
 - Computed Position, Heading, Speed, Slope, Power, and Temperature Results



Adventurer Deploys Rover from Lunar Module (LM) and Loads Equipment



Adventurer Views Heading, Speed, and Temperatures



Adventurer Activates Rover Switches and Uses Hand Controller for Driving



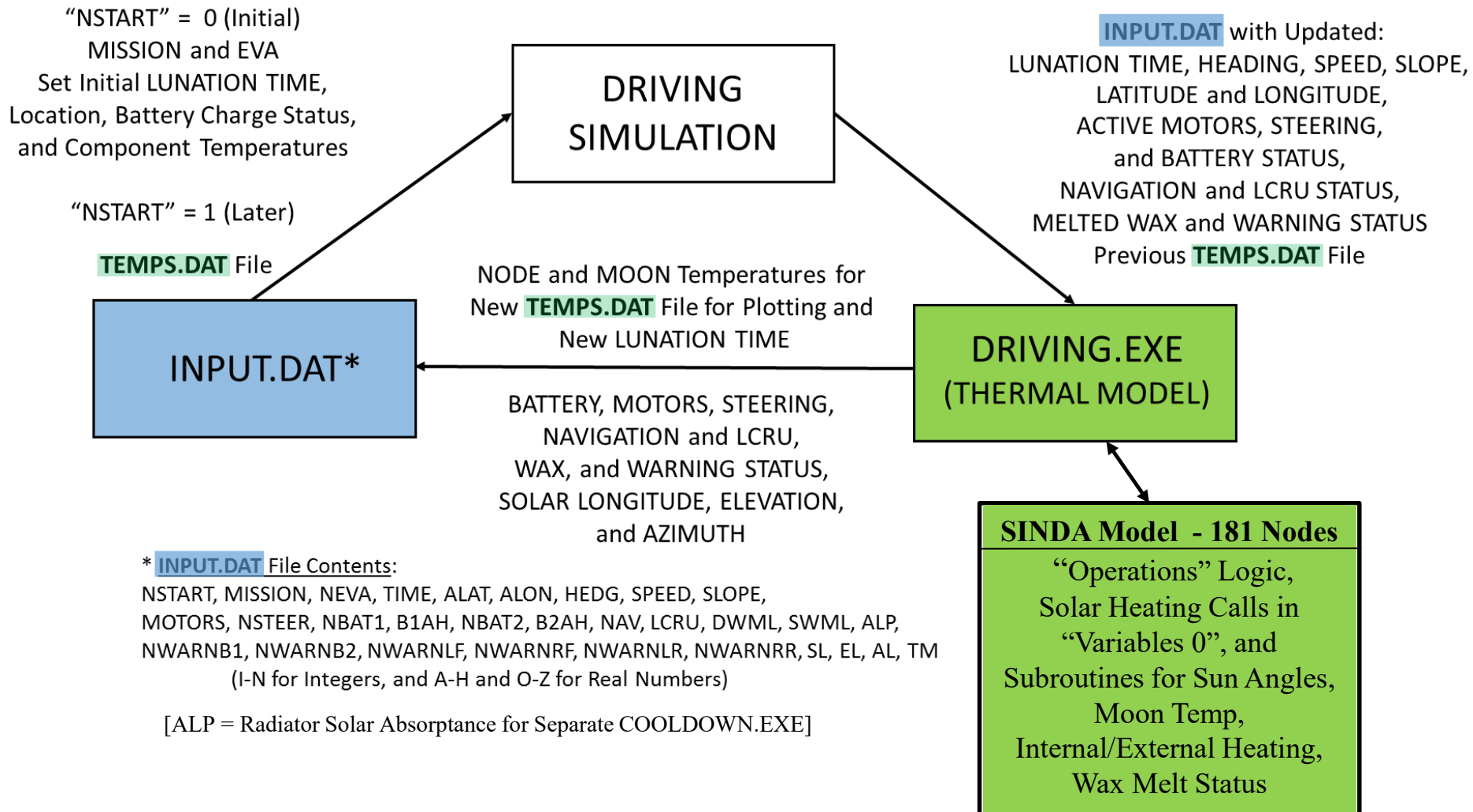
Adventurer Drives Rover to Pre-planned Station Stops for Exploration and Sample Collections





Interactive LUROVA™ Sim Game Thermal Model

- Simulation Game Thermal Model Increases STEM Exploration Realism
 - SINDA Provides Responsive Thermal Programming

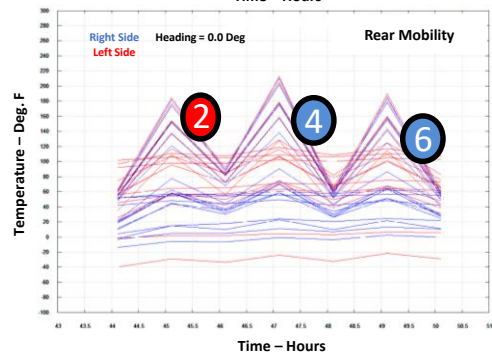
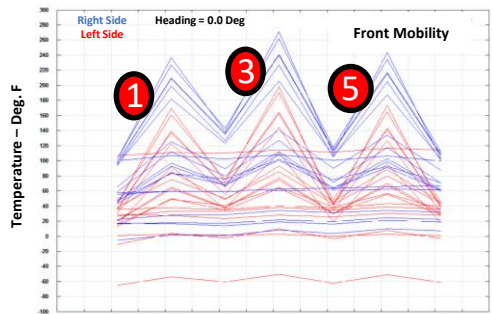


Simulated Operation During Driving & Cooldown Periods Verified

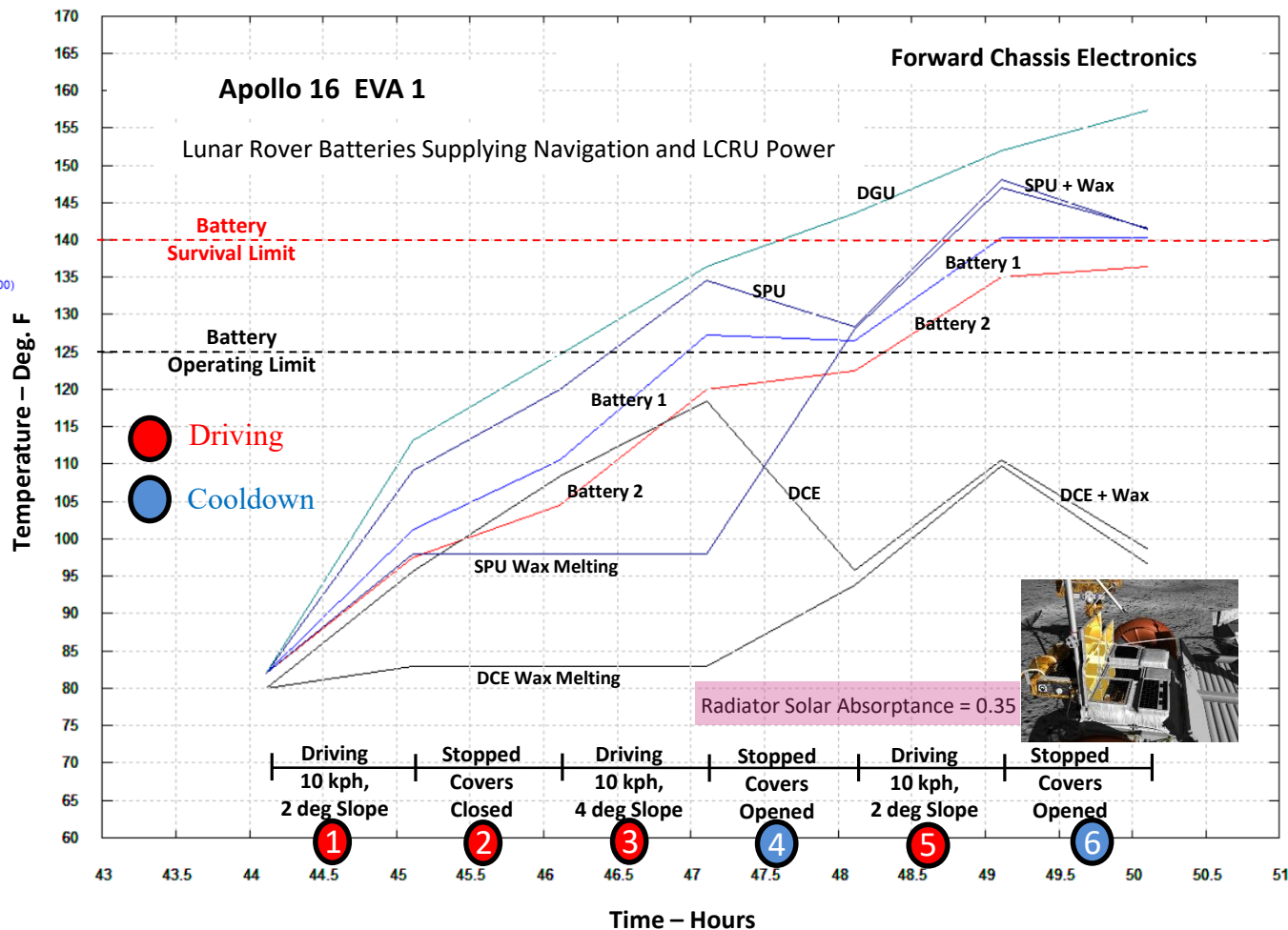
LRV Component Temperature Limits – Deg. F

Component	Minimum Survival	Minimum Operating	Maximum Operating	Maximum Survival
Batteries*	-15	40	125	140
Signal Processing Unit (SPU)	-65	30	130	185
Directional Gyro Unit (DGU)	-80	-65	160	200
Indicating Meters	-22	-22	160	160
Position Indicator	-65	-22	185	185
Drive Controller Electronics (DCE)	-20	0	159	180
Traction Drive**	-50	-25	400	450
Suspension Damper	-70	-65	400	450
Steering Motor	-50	-25	360	400
Wheel	-250	-200	250	250

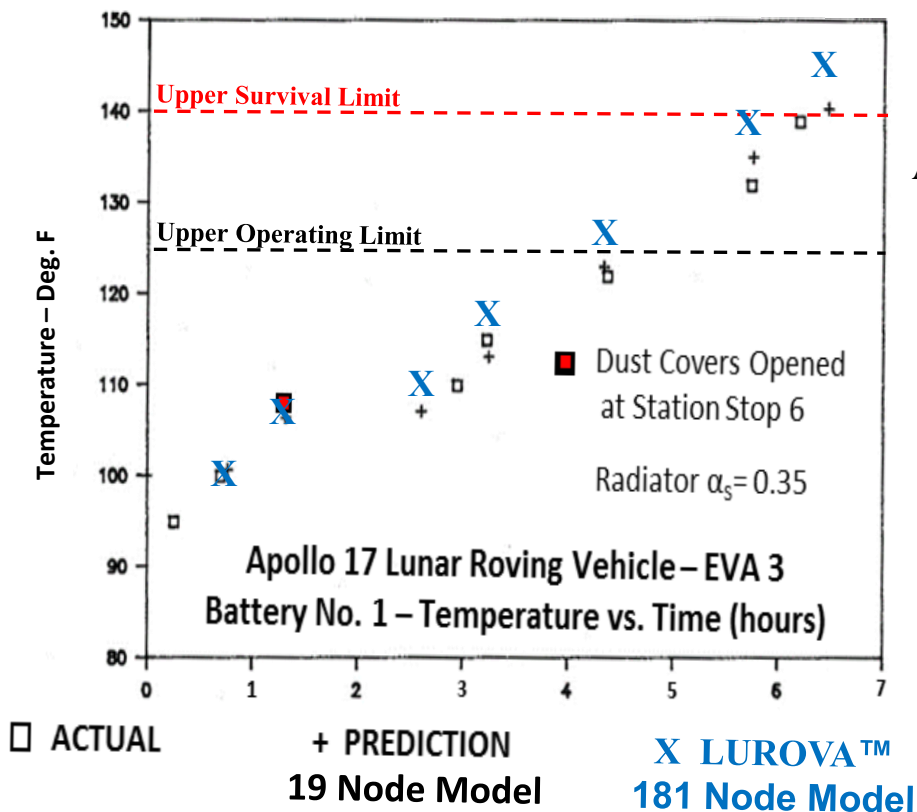
Astronauts Read Temperature On Display Panel - * Batteries ** Traction Drive (Start At 200)



LUROVA™ Thermal Model - Driving and Cooldown Verification

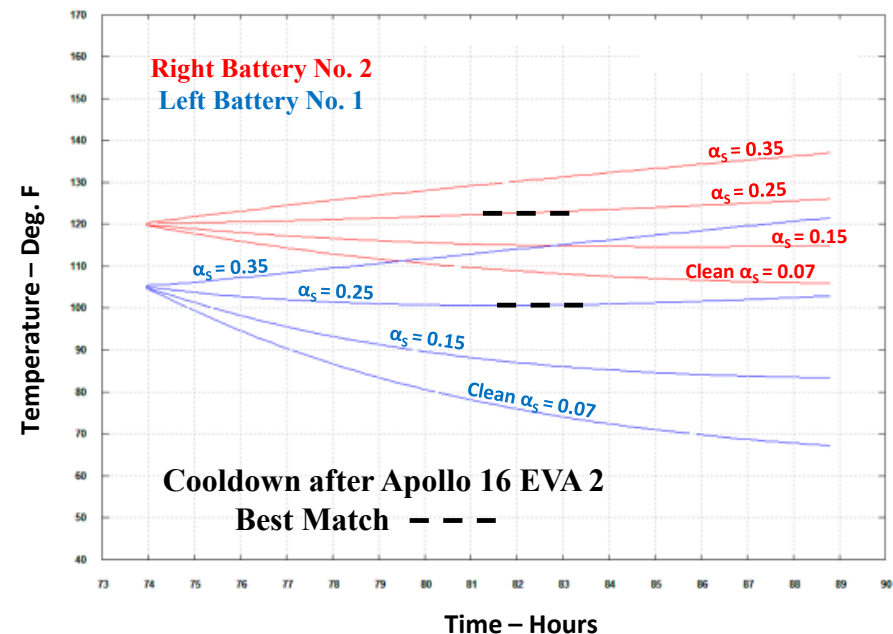


- **LUROVA™** Simulation Game Correlates Well With Last Rover Sortie
 - Lunar Dust Degradation Effects on Radiators Studied



Apollo Dust Brush

Astronaut Brushing
Dust from Radiator



Dust Degradation of Radiator Solar Absorptance - α_s

Future Plans for the LUROVA™ Simulation Game

- Finish Interactive **LUROVA™ STEM** Simulation Game Development
 - Opportunities for Student “Beta Testing” and Expansion for VR, “MAROVA”

➔ **Interactive LUROVA™ Process**

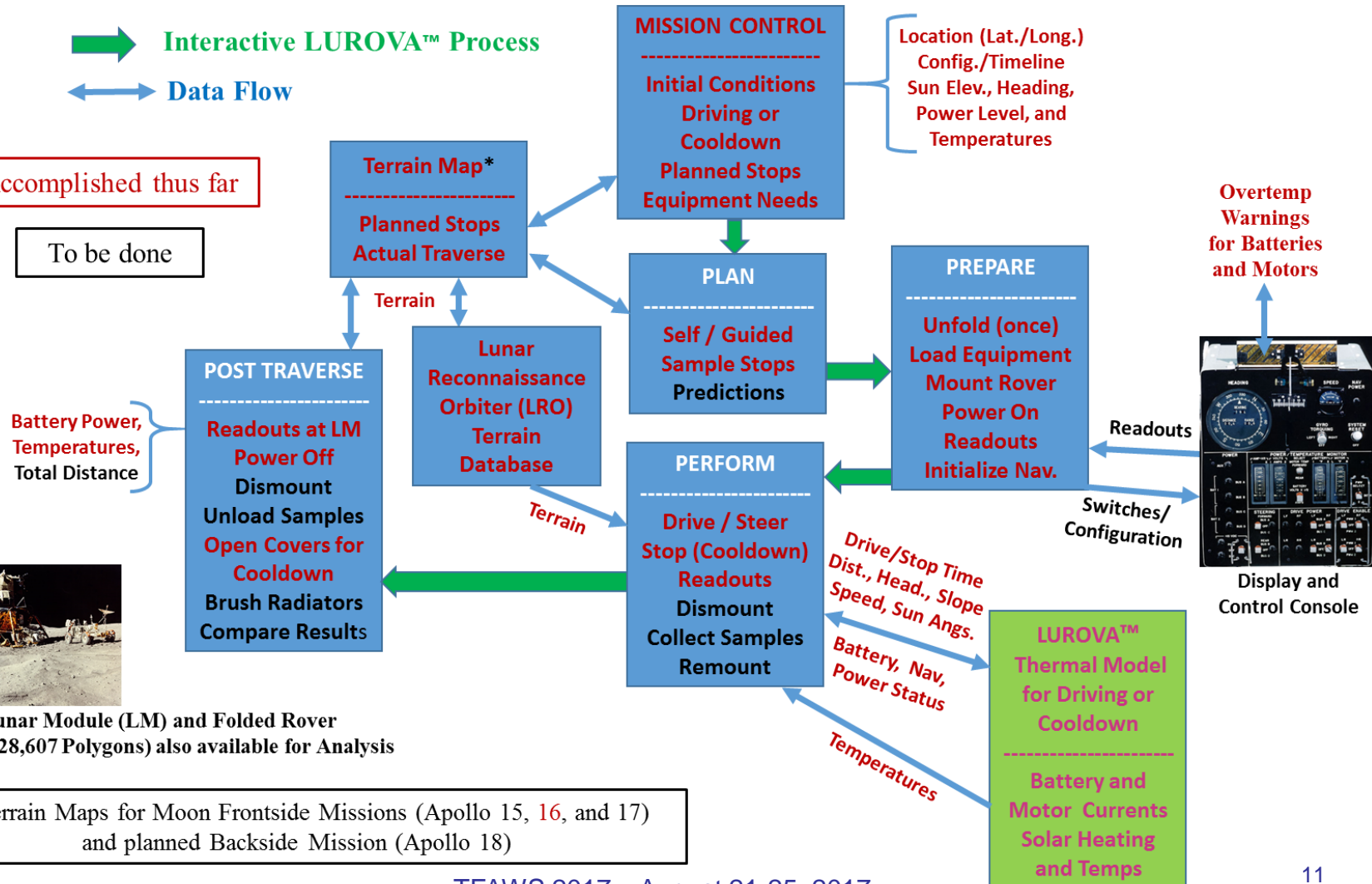
↔ **Data Flow**

Accomplished thus far

To be done



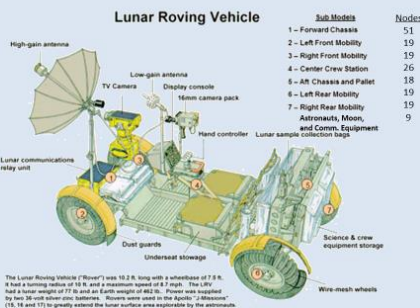
Detailed Lunar Module (LM) and Folded Rover Surface Model (328,607 Polygons) also available for Analysis



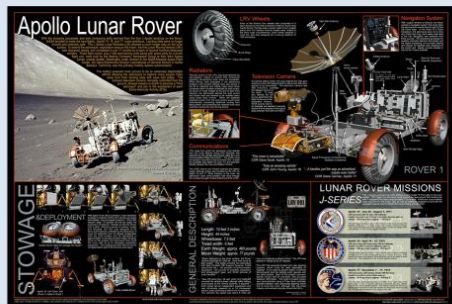
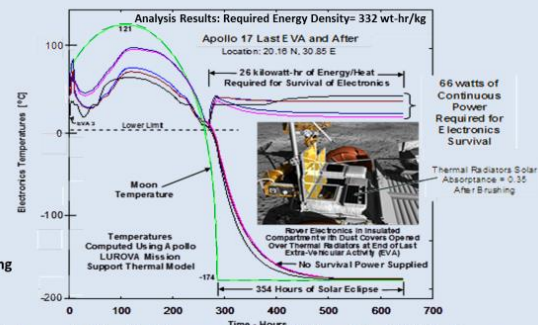
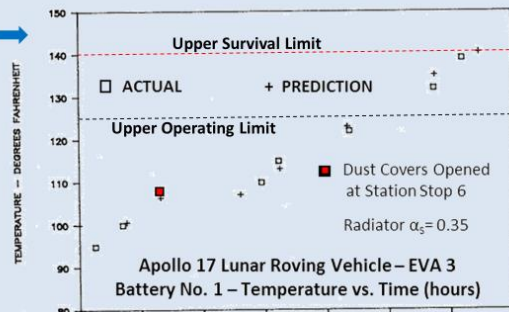
* - Terrain Maps for Moon Frontside Missions (Apollo 15, 16, and 17) and planned Backside Mission (Apollo 18)

Interactive LUROVA™ (Lunar ROVing Adventures) Simulation Game Being Developed for Realistic Student STEM Challenge and Moon Exploration Experience

(Contact Ron Creel, Apollo Lunar Roving Vehicle Team Member, at roving.ron@gmail.com for additional technical information)



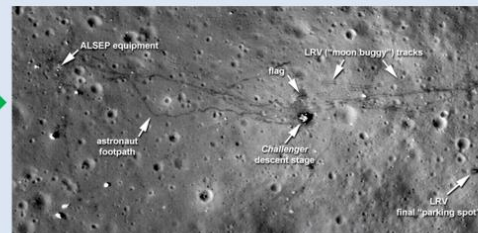
181 Node TVAC Test Correlated NASA Rover SINDA Thermal Model Used for Apollo 15 Mission Support



Render Engine Used for Poster, with Over 900,000 Surface Model Polygons



Lunar Reconnaissance Orbiter (LRO) Collecting Terrain Data Since 2009



LRO Terrain Data for Apollo 17

181 Node SINDA Thermal Model Combined with ~7800 Reduced Polygon Surfaces TRASY Model and LRO Terrain Data for Exploration Realism in LUROVA™



Test Your Moon Driving Skill in the LUROVA™ Simulation Game



STEM Simulation Game Provides Thermal Model with Variable Planning/Preparation, Mission Timing/Location, Rover Configuration and Power, Driving and Steering, Solar Heating, and Component Cooldown Dust Effects

